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ORIGINAL REPORT

COMPARISON OF MUSCLE STRENGTH, SPRINT POWER AND AEROBIC CAPACITY IN ADULTS WITH AND WITHOUT CEREBRAL PALSY

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Objective: To compare: (i) muscle strength, sprint power and maximal aerobic capacity; and (ii) the correlations between these variables in adults with and without cerebral palsy.

Design: Cross-sectional study.

Subjects: Twenty adults with and 24 without cerebral palsy.

Methods: Isometric and isokinetic knee extension strength, sprint power (mean power over the 30s (P30)), peak aerobic power output (PO_{peak}) and oxygen uptake (VO_{2peak}) were determined. Regression analysis was used to investigate correlations between parameters.

Results: Adults with cerebral palsy had significantly lower strength (53–69%) and P30 (67%) than adults without cerebral palsy, but similar PO_{peak} and VO_{2peak} . In adults without cerebral palsy the only significant correlations, albeit weak, were between P30 and isometric ($R^2=0.34$) or isokinetic strength ($R^2=0.20$), as well as the correlation between P30 and VO_{peak} ($R^2=0.26$) or PO_{peak} ($R^2=0.36$). Stronger correlations were found in the group with cerebral palsy between P30 and isometric ($R^2=0.52$) and isokinetic strength ($R^2=0.71$) and between P30 and VO_{peak} ($R^2=0.75$) or PO_{peak} ($R^2=0.94$).

Conclusion: In contrast to aerobic capacity, strength and P30 are reduced in (active) people with cerebral palsy. Stronger correlations were found between strength, P30 and PO_{peak} in adults with cerebral palsy. Therefore, muscle strength may be the limiting factor in adults with cerebral palsy for activities involving the lower extremities, such as cycling.

Key words: cerebral palsy; muscle strength; exercise test; exercise/*physiology.

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INTRODUCTION

Cerebral palsy (CP) is an umbrella term encompassing a group of non-progressive motor disorders in the developing brain that cause physical disability. Specific movement problems in CP

are associated with balance and walking, gross and fine motor control, and muscle spasticity (1, 2).

Movement problems are a possible reason why people with CP participate in fewer physical activities than age-matched healthy controls. Inactivity in people with disabilities can lead to a cycle of de-conditioning, adversely affecting the cardiovascular system, bone density, and muscular system, and leading to social isolation and decreased self-esteem (3–5). The level of physical activity of adolescents with CP is inversely related to age (6) and, therefore, adults with CP are most at risk for an inactive lifestyle (7). However, given the nature of the physical disability, there is no reason to expect that subjects with CP cannot benefit from a regular exercise programme or cannot break through the vicious circle of de-conditioning.

There is a paucity of literature related to physical capacity of adults with CP (8). Little is known about to what extent their physical capacity is limited. Important measures of physical capacity are muscle strength, sprint power, peak oxygen uptake (VO_{2peak}) and peak aerobic power output (PO_{peak}). In order to set up testing and training protocols, it is important to know how much these physical capacity measures are limited in adults with CP compared with adults without CP. Can we use similar test protocols as described for the general population or should we adjust the protocol? One of the difficulties in exercise testing in individuals with highly variable fitness levels is estimating the appropriate braking force and increments for the Wingate and graded exercise test, respectively. Predicting sprint power (based on the outcome of the strength test) and PO_{peak} (based on the outcome of the sprint test) can be very helpful for setting the correct resistance for the sprint and graded exercise test when there is no good indication of the physical capacity of a person. These equations are, however, not available for individuals with CP. The regression equations developed by Janssen et al. (9) have been used frequently for that purpose in wheelchair exercise studies (10–12).

In individuals with CP, maximal aerobic capacity may be limited by peripheral factors, such as muscle weakness or coordination deficits (13), and, to a lesser extent, by the cardiorespiratory system. The correlations between muscle strength, sprint power and maximal power output in CP may

consequently be stronger than in individuals without CP. If that is the case, it may not be worthwhile measuring all the physical capacity parameters. Furthermore, knowing which physical capacity parameters are limited in adults with CP compared with adults without CP, and what the correlations are between these parameters may provide guidance in setting up training programmes, e.g. whether the focus should be on strength or endurance training.

The objectives of this study are: (i) to compare physical capacity in adults with spastic CP (gross motor function I and II, unilateral and bilateral) and without CP; and (ii) to investigate whether the correlations between muscle strength of the lower extremities, sprint power and aerobic capacity during ergometer cycling in adults with CP are different from those in adults without CP. It is hypothesized that these correlations are stronger in adults with CP than in adults without CP due to limiting peripheral factors, such as muscle strength and coordination.

METHODS

Participants

A total of 20 subjects with spastic CP (4 females, 16 males; age range 18–49 years) and 21 males without CP (age range 19–55 years) participated in this study. Inclusion criteria for all individuals were: 18–65 years, no medical contra-indications for exercise testing; and for those with CP specifically: diagnosis of CP, level I or II on the Gross Motor Function Classification Scale (GMFCS) (14), familiar with cycling, cognitively able to understand and perform the tasks. Eight non-athletes, 2 athletes from the Dutch CP cycling team, and 10 athletes from the Dutch CP soccer team were included. Participants had unilateral ($n = 10$) or bilateral CP ($n = 10$). Fifteen subjects had a GMFCS level I and 5 a GMFCS level II. Prior to the first exercise test, participants were examined by a rehabilitation physician in order to determine contra-indications for (maximal) exercise testing. Based on this examination, all subjects were included in this study. Written informed consent for participation was obtained for all participants. The study was approved by the medical ethics committee of the VU University Medical Center.

Design

Prior to testing, body mass and height of the participants were measured to calculate the body mass index (BMI, kg/m^2). Each subject performed a set of 3 tests with a 30-min rest period between tests. The tests included an isometric and isokinetic leg muscle strength test, a Wingate test and a graded exercise test on a bicycle ergometer. Thereafter, correlations between peak torque of the lower extremities, sprint power and peak aerobic power and $\text{VO}_{2\text{peak}}$ were investigated.

Muscle strength

Both isometric and isokinetic strength were implemented in the test in order to determine which component of strength correlated best with sprint power and aerobic capacity. Isometric strength tests are more feasible for people with CP (15); however, isokinetic muscle strength may correlate better with dynamic cycling activity. Persons with CP performed tests to measure knee extension strength of both legs (impaired and less impaired), while those without CP performed knee extension measurements of the right leg only. Measurements of muscle strength were conducted with a Biodex dynamometer (Biodex Medical Systems Inc., New York, USA). Participants were seated on the dynamometer at a comfortable hip angle, ranging from 90° to 110° , with the centre of the knee joint aligned with the centre of rotation of the equipment. The calf was secured against the attachment pad, which was adjustable and parallel to the longitudinal axis of the

lower leg. The attachment pad was placed distally as far as possible without compressing the tendo calcaneus during movement. To prevent trunk and hip movement during the measurements, straps were placed around the pelvis, the trunk and the upper part of the tested leg. Before measurement, participants performed one exertion for extension and flexion to familiarize themselves with the test procedure.

Isometric strength. Isometric strength was measured with the knee in 60° flexion, with full extension being 0° . Maximal isometric torque (Nm) of knee extensors was measured 3 times during 5 s, with a 30-s rest between each contraction. The mean value of these 3 measurements was used for evaluation of maximal isometric strength.

Isokinetic strength. Isokinetic strength was measured at an angular velocity of $60^\circ/\text{s}$, which has been found to be a feasible speed for most adults with CP (15, 16), and with a range of motion of 70° , starting with the knee flexed at 90° and ending in extension (160°). Maximal isokinetic torque (Nm) of knee extensors was measured 3 times with a 30-s rest between measurements. The mean value of the 3 measurements was used for evaluation of maximal isokinetic strength. If the subject had a bilateral CP, the leg with the highest strength level was considered the less-impaired leg.

Sprint power

Sprint power was determined using the Wingate test protocol (17), which consists of a 30-s cycling test at all-out effort against a constant braking force. Participants sat on an Excalibur bicycle ergometer (Lode, Groningen, The Netherlands), with the feet secured to the pedals. After a 5-min warm-up at 60 rpm and a work rate of 100 W, participants were encouraged to pedal as fast as possible against a fixed resistance. The braking power was set according to the following equation:

$$P_{\text{brake}} = (2 \times \pi \times \text{RPM}/60) \times T,$$

in which RPM = pedal revolution and T = braking torque.

The braking torque was set at 70% of the body mass of the participant, expressed in Nm. However, based on the subject's cycling ability and strength score, this percentage could be lowered. After completing the test each participant cycled for 2–3 min at a self-chosen pace and intensity in order to recover. With the use of integrated Wingate software (version 1.0.9, Lode, Groningen, The Netherlands), peak power (P_{max}) and mean power over the 30 s (P_{30}) was calculated.

Aerobic power

Each participant performed a graded exercise test on the Excalibur bicycle ergometer using an incremental protocol. The participants with CP were assigned to an easy, moderate or heavy protocol, depending on their cycling ability and scores on the Wingate test. First, the participant performed a warm-up of 3 min at a resistance of 40, 50 or 60 W, depending on the chosen protocol. After the warm-up they had a 3-min rest and thereafter the actual incremental protocol started at 20 W. Depending on the protocol, workloads increased every min by 10, 15 or 20 W. After 6 min, the workload was maintained for 3 min (steady-state measurement at 80, 110 or 140 W) and, thereafter, the workload increased again every minute until exhaustion, which was defined as the workload at which the subjects could no longer maintain the chosen speed. For participants without CP, the test started with a 3-minute warm-up at 100 W. Thereafter, increments of 30 W were added to the power output every 2 min until the subject was exhausted and no longer able to maintain the required power output.

VO_2 was measured continuously with the Oxycon alpha (CareFusion, Houten, The Netherlands), calibrated prior to each test with standard gases and volume. $\text{VO}_{2\text{peak}}$ was determined as the highest 30-s mean value attained during the test. PO_{peak} was determined as the highest work rate that the subjects could maintain for at least 30 s. Heart rate (bpm) was measured with a Polar heart monitor (Polar electro oy, Kempele, Finland). Maximal heart rate (HR_{max}) was the highest 5-s mean value found during the test. As objective criteria for maximal exercise, we used the peak heart rate as a percentage of predicted heart

rate (at or above 95% of the value 220 minus age in years) and the respiratory exchange ratio (RER) of > 1.10 (18).

Statistics

Differences in personal characteristics and physical capacity parameters were tested between groups (with vs without CP, GMFCS I vs GMFCS II, unilateral vs bilateral) with an independent *t*-test and a χ^2 test.

Linear regression models were developed for the groups with CP and without CP separately in order to determine the correlations between outcome variables within each of the groups. With univariate modelling the correlations between sprint power and the strength parameters were established. Secondly, PO_{peak} and VO_{2peak} were used as dependent variables in a linear regression analysis with the strength or sprint variables as independent variables. Significance was set at $p < 0.05$ for all statistical tests.

RESULTS

Comparison between groups

Participants with and without CP did not differ in age and BMI, but participants without CP were taller and heavier than those with CP (Table I). Therefore, the physical capacity measures were all expressed relative to body mass.

One person with CP was not able to perform the isometric strength test, due to spasticity of the quadriceps muscles during testing. Five subjects with CP were not able to perform the isokinetic strength test correctly during 1 or 2 repetitions; the (mean) value of the correctly performed repetition(s) was calculated and used in the analyses. All participants were able to perform the sprint test and graded exercise test.

Descriptives of the physical outcome measures between the groups with and without CP, with GMFCS level I and II, and with unilateral or bilateral CP are shown in Table I.

Muscle strength. The group with CP showed a significantly lower isokinetic knee extension strength and isometric knee extension strength compared with the group without CP. The group with CP showed 53% and 69% of the isokinetic and isometric knee extension strength of the group without CP, respectively. Individuals with GMFCS level I or with a unilateral CP showed a significantly higher isokinetic knee extension strength compared with subjects with GMFCS level II or a bilateral CP. Differences in isometric strength within the CP group were less pronounced.

Sprint power. A significantly lower sprint power was found for the group with CP compared with the group without CP, and for those with GMFCS level II and bilateral CP. Persons with CP had only 67% of the sprint power of subjects without CP (Fig. 1).

Aerobic capacity. The mean peak heart rate was $94.9 \pm 8.3\%$ of the age-predicted maximum heart rate values in the group with CP and $96.5 \pm 5.3\%$ in the group without CP. Peak heart rate did not differ significantly between subjects with and without CP (CP: 180.7 ± 11.3 bpm; without CP: 180.3 ± 13.0 bpm). All participants had an RER > 1.10 , indicating maximal performance.

PO_{peak} was significantly different between subjects with GMFCS level I and II, and between those with unilateral and bilateral CP. However, the PO_{peak} was not significantly different between the groups with and without CP. The mean PO_{peak} for subjects with CP was 89% of the PO_{peak} value for subjects without CP.

The VO_{2peak} only differed significantly between the GMFCS I and II groups. The VO_{2peak} was almost similar in the groups

Table I. Differences between participant characteristics and physical capacity outcome measures between groups

	GMFCS I	GMFCS II	p-value GMFCS I vs II	Unilateral	Bilateral	p-value unilateral vs bilateral	Total group with CP	Group without CP	p-value CP vs without CP
Numbers of participants	15	5		10	10		20	24	
Gender, % men	93	40	0.01	90	70	0.26	80	100	0.03
Age, years, mean (SD)	25.9 (9.7)	37.4 (10.7)	0.04	24.6 (10.3)	33.0 (10.4)	0.08	28.8 (11.0)	33.0 (12.8)	0.27
Height, metres, mean (SD)	1.79 (0.07)	1.67 (0.12)	0.02	1.78 (0.08)	1.74 (0.12)	0.38	1.76 (0.10)	1.83 (0.08)	0.02
Body mass, kg, mean (SD)	71.5 (7.2)	60.2 (9.8)	0.03	71.5 (8.0)	65.9 (9.8)	0.23	69.0 (9.1)	76.5 (8.9)	0.01
Body mass index, kg/metre ² , mean (SD)	22.4 (2.6)	21.5 (2.2)	0.65	22.6 (2.8)	21.7 (2.2)	0.52	22.3 (2.4)	22.8 (1.6)	0.37
Elite athlete (paralympic cycling or soccer), %	73	20	0.04	80	40	0.07	60	–	–
Isokinetic knee extension strength, Nm/kg, mean (SD)									
Impaired leg	1.5 (0.5)	0.8 (0.3)	0.01	1.6 (0.4)	1.1 (0.5)	0.05	1.3 (0.5)	–	–
Less impaired leg	1.9 (0.5)	0.9 (0.3)	0.001	2.0 (0.3)	1.2 (0.6)	0.001	1.6 (0.6)	3.0 (0.5)	<0.001
Isometric knee extension strength, Nm/kg, mean (SD)									
Impaired leg	2.3 (0.6)	2.1 (0.6)	0.52	2.1 (0.6)	2.4 (0.6)	0.21	2.2 (0.6)	–	–
Less impaired leg	2.6 (0.5)	1.9 (0.4)	0.007	2.6 (0.6)	2.3 (0.6)	0.33	2.5 (0.6)	3.6 (0.7)	<0.001
P30, W/kg, mean (SD)	6.5 (1.9)	2.6 (0.5)	<0.001	6.9 (2.1)	4.2 (2.0)	0.008	5.6 (2.4)	8.4 (0.6)	<0.001
VO_{2peak} , ml/min/kg, mean (SD)	44.5 (10.9)	35.1 (5.6)	0.09	46.0 (11.9)	38.3 (7.9)	0.11	42.2 (10.6)	44.6 (6.8)	0.39
PO_{peak} , W/kg, mean (SD)	3.6 (0.9)	1.9 (0.3)	<0.001	3.8 (0.9)	2.6 (0.9)	0.008	3.2 (1.1)	3.6 (0.6)	0.13

SD: standard deviation; GMFCS: Gross Motor Function Classification Scale; CP: cerebral palsy; PO_{peak} : peak aerobic power output.

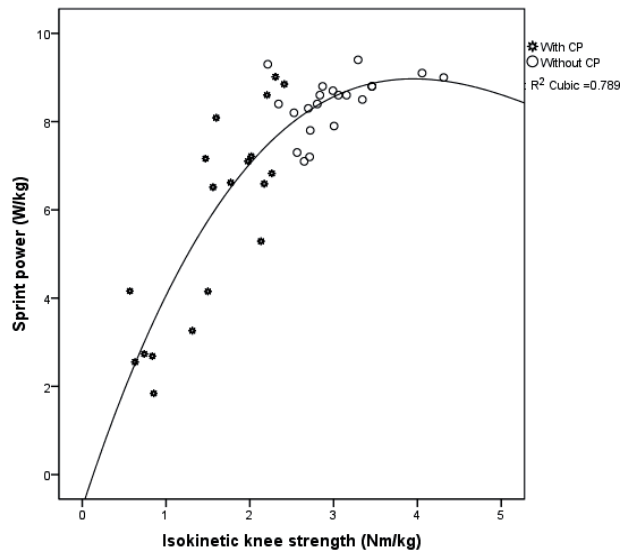


Fig. 1. Isokinetic knee extension strength vs mean sprint power for adults with cerebral palsy (CP) (stars) and without CP (circles).

with and without CP, i.e. the group with CP showed 95% of the VO_{2peak} value of the group without CP.

Correlations between physical capacity parameters

Correlations between the physical capacity parameters for the participants with and without CP are shown in Tables II and III. In general, the less impaired leg of the participants with CP showed stronger correlations between physical capacity parameters compared with the more impaired leg. The isokinetic strength parameters showed stronger correlations with P30 and PO_{peak} than isometric strength.

Moderate to strong correlations were found in the group with CP regarding sprint power and isometric ($R^2=0.52$) and isokinetic extension strength ($R^2=0.71$) of the less impaired leg. The correlation between sprint power and PO_{peak} ($R^2=0.94$) and sprint

power and VO_{2peak} ($R^2=0.75$) was (very) strong. In the participants without CP the correlations between sprint power and isometric ($R^2=0.34$) or isokinetic knee extension strength ($R^2=0.20$) were weak. A weak correlation was also found between sprint power and maximal power output ($R^2=0.36$) and between sprint power and VO_{2peak} ($R^2=0.26$) in the group without CP. In general, participants with CP showed stronger correlations between the physical capacity parameters than participants without CP.

DISCUSSION

This is the first study to compare physical capacity and the correlations between physical capacity measures in adults with and without CP. The group with CP had reduced knee extension strength and sprint power compared with a group without CP; however, no significant differences were found in aerobic capacity (VO_{2peak} and PO_{peak}). Stronger correlations were found between muscle strength, sprint power and peak power output in adults with CP compared with adults without CP.

Comparison between groups

VO_{2peak} and PO_{peak} values for the group with CP were higher in our study (2.9 l/min or 42.2 ml/min/kg; 223 W) compared with other studies (1.93 l/min or 26.8 ml/min/kg and 2.19 l/min or 31.5 ml/min/kg; 144 W) (18, 19), which may be due to the inclusion of a subgroup of athletes ($n=12$). Muscle strength and sprint power may also be different in our group with CP; however, this could not be compared with previous studies because different protocols were used (strength) or no information was available (sprint). As expected, the physical capacity outcomes were higher for the group with GMFCS level I compared with GMFCS level II. The group with unilateral CP had a better physical capacity compared with the group with bilateral CP, except for the isometric knee strength.

A notable finding was that the group with CP had significantly lower muscle strength (53–69% of the reference values)

Table II. Regression equations with muscle strength as independent variables and sprint power (P30), peak oxygen uptake (VO_{2peak}) and peak aerobic power output (PO_{peak}) as dependent variables

Dependent variable	Independent variable	Adults with CP, more impaired leg			Adults with CP, less impaired leg			Adults without CP		
		Beta (SE)	p-value	R ²	Beta (SE)	p-value	R ²	Beta (SE)	p-value	R ²
P30, W/kg	Constant	1.46 (1.07)			0.67 (0.84)			6.73 (0.78)		
	Isok.ext. strength, Nm/kg	3.25 (0.76)	<0.001	0.52	3.19 (0.49)	<0.001	0.71	0.56 (0.25)	0.04	0.20
P30, W/kg	Constant	2.24 (1.98)			-1.64 (1.67)			6.51 (0.63)		
	Isom.ext. strength, Nm/kg	1.49 (0.86)	0.10	0.14	2.94 (0.66)	<0.001	0.52	0.53 (0.17)	0.006	0.34
VO_{2peak} , ml/min/kg	Constant	27.81 (4.61)			25.73 (1.17)			37.95 (9.01)		
	Isok.ext. strength, Nm/kg	11.84 (3.26)	0.002	0.44	11.09 (2.45)	<0.001	0.55	2.22 (2.96)	0.46	0.03
VO_{2peak} , ml/min/kg	Constant	26.11 (8.50)			14.30 (8.12)			39.27 (8.01)		
	Isom.ext. strength, Nm/kg	7.20 (3.67)	0.07	0.18	11.38 (3.23)	0.002	0.41	1.46 (2.16)	0.51	0.02
PO_{peak} , W/kg	Constant	1.35 (0.51)			0.97 (0.41)			2.90 (0.84)		
	Isok.ext. strength, Nm/kg	1.45 (0.36)	0.001	0.48	1.44 (0.24)	<0.001	0.68	0.24 (0.27)	0.39	0.04
PO_{peak} , W/kg	Constant	1.79 (0.91)			-0.10 (0.75)			3.00 (0.74)		
	Isom.ext. strength, Nm/kg	0.63 (0.39)	0.13	0.12	1.34 (0.30)	<0.001	0.53	0.17 (0.20)	0.41	0.04

Isok.ext.: isokinetic extension strength; Isom.ext.: isometric extension strength; SE: standard error; CP: cerebral palsy.

Table III. Regression equations with sprint power (mean power over the 30s; P30) as independent variables and peak oxygen uptake (VO_{2peak}) and peak aerobic power output (PO_{peak}) as dependent variables

Dependent variable	Independent variable	Adults with CP			Adults without CP		
		Beta (SE)	p-value	R ²	Beta (SE)	p-value	R ²
VO_{2peak} , ml/min/kg	Constant	21.19 (3.14)			-0.93 (17.49)		
	P30, W/kg	3.78 (0.52)	<0.001	0.75	5.41 (2.07)	0.02	0.26
PO_{peak} , W/kg	Constant	0.75 (0.16)			-1.36 (1.52)		
	P30, W/kg	0.44 (0.03)	<0.001	0.94	0.59 (0.18)	0.004	0.36

SE: standard error; CP: cerebral palsy.

and sprint power (67% of the reference values) compared with the group without CP, but had similar VO_{2peak} (95% of the reference value) or PO_{peak} (89% of the reference value). The finding that the aerobic exercise capacity of adults with CP is not limited is important, since aerobic exercise capacity has proven to be a good indicator of health (20), and normal values can thus be achieved by training. The more explosive character and/or higher speeds of the strength and sprint test might explain why these parameters are more impaired in adults with CP compared with the parameters measured during the graded exercise test. Adults with CP have a lower muscle volume, different type of muscle fibres, and coordination problems due to (velocity-dependent) spasticity, limited selective muscle control and co-contraction (21). This might have led to the lower strength and sprint power values found in the present study.

Correlations

The associations between muscle strength, sprint power and peak aerobic capacity were moderate to strong in adults with CP, with stronger associations for the less impaired leg. Since the correlations between muscle strength, sprint power and peak aerobic capacity were slightly stronger in the less impaired leg, it can be concluded that muscle strength of the less impaired, i.e. stronger leg, is a more important determining factor for cycling performance.

Associations between muscle strength and sprint power or peak aerobic capacity were stronger for isokinetic strength compared with isometric strength. This may be due to the greater resemblance of isokinetic muscle strength to the dynamic muscle action in cycling and because a maximal isometric contraction is only indicative of the capacity to produce force at that particular position and muscle length. Therefore it cannot necessarily be extrapolated to conditions of dynamic muscle action (22). No direct comparisons can be made with other studies because no other study has investigated the correlations between the same test parameters in adults with CP.

In contrast to the results of the group with CP, correlations between strength, sprint power and peak aerobic capacity were weak to moderate in the group without CP. Some studies have been performed to analyse these correlations in able-bodied subjects. Kin-Isler et al. (23) studied the correlation between isokinetic knee strength and sprint performance in 28 American football players. In this able-bodied group, the correlation coefficients found between strength and sprint power were

approximately 0.50, i.e. higher than in the present study in adults without CP, but lower than in adults with CP. Al-Haza et al. (24) also found a weak correlation ($r=0.45$) between P30 and VO_{2peak} in elite soccer players, while Gometti et al. (25) indicated that isokinetic muscle strength was not related to 30-m running sprint performances in amateur, sub-elite and elite soccer players.

In people with other physical limitations strong correlations have also been found between the physical capacity parameters. Janssen et al. (9) found strong correlations between isometric strength and sprint power ($R^2=0.75$) and sprint power and PO_{peak} ($R^2=0.81$) in upper-extremity exercise for people with a spinal cord injury. Kofsky et al. (26) found that high levels of isokinetic and static arm strength are associated with a high VO_{2peak} in individuals with lower-limb muscle dysfunction.

An explanation for the different findings between people with a disability and the able-bodied group might be the larger variability and lower values of physical capacity of subjects with a disability. However, the range of muscle strength was similar in the groups with (isokinetic strength 0.57–2.41 Nm/kg) and without CP (2.21–4.31 Nm/kg), i.e. the muscle strength among those without CP also varied considerably. As shown in Fig. 1, the graph of strength and sprint power levels off at the higher range of muscle strength. Therefore, those with a greater strength, i.e. the group without CP, show a weaker correlation with sprint capacity. Thus an increase in muscle strength above a certain level will not increase power output during sprint or peak exercise. This is in contrast to the findings in our group with CP, in which lower strength seems to be a limiting factor for sprint power and peak aerobic capacity.

A previous study (27) also showed stronger correlations between explosive or isometric leg strength and sprint power during the Wingate test in non-disabled groups with a lower physical capacity compared with those with a higher physical capacity, i.e. women vs men and sedentary vs regularly active people. Muscle strength might, therefore, be the limiting factor in the group with a low physical capacity to perform activities such as cycling, although coordination problems may also play an important role in the group with CP. Johnston et al. (4) found that the joint kinematics during cycling in adolescents with CP were different from those for adolescents without CP. They suggested that these differences in joint kinematics may have been due to decreased strength, but also to a decreased motor control. Participants with CP in their study showed prolonged muscle activity and increased co-contraction of agonists and

antagonists during cycling. As a result of the greater amount of energy required to be expended in order to overcome the constant increase in muscle tone during cycling, cycling efficiency was found to be significantly lower for subjects with CP than for those without CP (4, 28). However, relative $\text{VO}_{2\text{peak}}$ and PO_{peak} were not different between the groups in the present study, indicating that highly trained adults with CP can reach the same aerobic fitness levels as non-disabled individuals when sufficiently active.

Implications and limitations

Although reduced knee extension strength and sprint power were found in the participants with CP, their aerobic capacity was similar to that of the reference group. These results suggest that people with CP are able to achieve good aerobic capacity when sufficiently active, which is important regarding the benefits of physical fitness for health.

The strength, sprint and aerobic exercise tests are feasible in adults with CP, as described previously, although measuring isometric strength is more feasible than measuring isokinetic strength in this group (15). Isokinetic strength showed stronger associations with dynamic activity, such as cycling, especially for the more impaired leg. If the focus of interest is not only strength itself, but also the effect of strength on daily life (dynamic) activities, such as cycling or walking, testing isokinetic strength is recommended.

Muscle strength seems to be the limiting factor for cycling performance in the group with CP. Therefore, strength and power training may be beneficial in this group, although the challenge is to transfer the increase in strength to functional activities, such as cycling. For example, previous studies have shown that strength training in children and adolescents with CP results in an increase in strength, although this is not accompanied by improvements in mobility (29). To better understand the correlation between muscle strength and cycling performance, future studies should focus on whether strength training improves cycling performance and/or whether cycling training improves muscle strength in people with CP.

The regression equations in Tables II and III can be used to predict the performance of an individual with CP, in order to set the correct resistance for the sprint and maximal exercise test. Since sprint power and peak power output are strongly related, it may not be necessary to perform both tests. Depending on the availability of equipment and time, i.e. a sprint test takes much less time, but requires a special bicycle ergometer and software, one of the tests can be chosen. However, when $\text{VO}_{2\text{peak}}$ is of interest in addition to PO_{peak} , the maximal exercise test is recommended.

This study has several limitations. One potential limitation is the distribution of GMFCS level (more GMFCS level I) and athletes (more athletes) within the group with CP.

Another limitation was that the test protocols for the sprint test and graded exercise test were not standardized for all participants. It was not possible to use a single standardized protocol, due to the large variation in physical capacity within the CP group and between the groups with and without CP. However, if the protocol is adapted to the individual's capac-

ity, a more valid evaluation of their real performance capacity can be made.

In conclusion, muscle strength and sprint power are reduced in (physically active) people with CP, while aerobic capacity (PO_{peak} and $\text{VO}_{2\text{peak}}$) is similar between the groups with and without CP. Stronger correlations were found between muscle strength and sprint power and between sprint power and peak power output in adults with CP compared with adults without CP. The results of this study suggest that anaerobic and aerobic activities of the lower limb are limited more by reduced muscle strength in adults with CP.

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